Appendix 4

Summaries from international reports

International Energy Agency

Golden Rules for a Golden Age of Gas

2012

Natural gas is poised to enter a golden age, but will do so only if a significant proportion of the world's vast resources of unconventional gas – shale gas, tight gas and coalbed methane – can be developed profitably and in an environmentally acceptable manner. Advances in upstream technology have led to a surge in the production of unconventional gas in North America in recent years, holding out the prospect of further increases in production there and the emergence of a large-scale unconventional gas industry in other parts of the world, where sizeable resources are known to exist. The boost that this would give to gas supply would bring a number of benefits in the form of greater energy diversity and more secure supply in those countries that rely on imports to meet their gas needs, as well as global benefits in the form of reduced energy costs.

Yet a bright future for unconventional gas is far from assured: numerous hurdles need to be overcome, not least the social and environmental concerns associated with its extraction. Producing unconventional gas is an intensive industrial process, generally imposing a larger environmental footprint than conventional gas development. More wells are often needed and techniques such as hydraulic fracturing are usually required to boost the flow of gas from the well. The scale of development can have major implications for local communities, land use and water resources. Serious hazards, including the potential for air pollution and for contamination of surface and groundwater, must be successfully addressed. Greenhouse-gas emissions must be minimised both at the point of production and throughout the entire natural gas supply chain. Improperly addressed, these concerns threaten to curb, if not halt, the development of unconventional resources.

The technologies and know-how exist for unconventional gas to be produced in a way that satisfactorily meets these challenges, but a continuous drive from governments and industry to improve performance is required if public confidence is to be maintained or earned. The industry needs to commit to apply the highest practicable environmental and social standards at all stages of the development process. Governments need to devise appropriate regulatory regimes, based on sound science and high-quality data, with sufficient compliance staff and guaranteed public access to information. Although there is a range of other factors that will affect the development of unconventional gas resources, varying between different countries, our judgement is that there is a critical link between the way that governments and industry respond to these social and environmental challenges and the prospects for unconventional gas production.

We have developed a set of "Golden Rules", suggesting principles that can allow policymakers, regulators, operators and others to address these environmental and social impacts. We have called them Golden Rules because their application can bring a level of environmental performance and public acceptance that can maintain or earn the industry a "social licence to operate" within a given jurisdiction, paving the way for the widespread development of unconventional gas resources on a large scale, boosting overall gas supply and making the golden age of gas a reality.

The Golden Rules underline that full transparency, measuring and monitoring of environmental impacts and engagement with local communities are critical to addressing public concerns. Careful choice of drilling sites can reduce the above-ground impacts and most effectively target the productive areas, while minimising any risk of earthquakes or of fluids passing between geological strata. Leaks from wells into aquifers can be prevented by high standards of well design, construction and integrity testing. Rigorous assessment and monitoring of water requirements (for shale and tight gas), of the quality of produced water (for coalbed methane) and of waste water for all types of unconventional gas can ensure informed and stringent decisions about water handling and disposal. Production related emissions of local pollutants and greenhouse-gas emissions can be reduced by investments to eliminate venting and flaring during the well-completion phase.

We estimate that applying the Golden Rules could increase the overall financial cost of development a typical shale-gas well by an estimated 7%. However, for a larger development project with multiple wells, additional investment in measures to mitigate environmental impacts may be offset by lower operating costs.

In our Golden Rules Case, we assume that the conditions are in place, including approaches to unconventional gas development consistent with the Golden Rules, to allow for a continued global expansion of gas supply from unconventional resources, with far-reaching consequences for global energy markets. Greater availability of gas has a strong moderating impact on gas prices and, as a result, global gas demand rises by more than 50% between 2010 and 2035. The increase in demand for gas is equal to the growth coming from coal, oil and nuclear combined, and ahead of the growth in renewables. The share of gas in the global energy mix reaches 25% in 2035, overtaking coal to become the second-largest primary energy source after oil.

Production of unconventional gas, primarily shale gas, more than triples in the Golden Rules Case to 1.6 trillion cubic metres in 2035. This accounts for nearly two-thirds of incremental gas supply over the period to 2035, and the share of unconventional gas in total gas output rises from 14% today to 32% in 2035. Most of the increase comes after 2020, reflecting the time needed for new producing countries to establish a commercial industry. The largest producers of unconventional gas over the projection period are the United States, which moves ahead of Russia as the largest global natural gas producer, and China, whose large unconventional resource base allows for very rapid growth in unconventional production starting towards 2020. There are also large increases in Australia, India, Canada and Indonesia. Unconventional gas production in the European Union, led by Poland, is sufficient after 2020 to offset continued decline in conventional output.

Global investment in unconventional production constitutes 40% of the $6.9 trillion (in year-2010 dollars) required for cumulative upstream gas investment in the Golden Rules Case. Countries that were net importers of gas in 2010 (including the United States) account for more than three-quarters of total unconventional upstream investment, gaining the wider economic benefits associated with improved energy trade balances and lower energy prices. The investment reflects the high number of wells required: output at the levels anticipated in the Golden Rules Case would require more than one million new unconventional gas wells worldwide between now and 2035, twice the total number of gas wells currently producing in the United States.

The Golden Rules Case sees gas supply from a more diverse mix of sources of gas in most markets, suggesting growing confidence in the adequacy, reliability and affordability of natural gas. The developments having most impact on global gas markets and security are the increasing levels of unconventional gas production in China and the United States, the former because of the way that it slows the growth in Chinese import needs and the latter because it allows for gas exports from North America. These developments in tandem increase the volume of gas, particularly liquefied natural gas (LNG), looking for markets in the period after 2020, which stimulates the development of more liquid and competitive international markets. The share of Russia and countries in the Middle East in international gas trade declines in the Golden Rules Case from around 45% in 2010 to 35% in 2035, although their gas exports increase by 20% over the same period.

In a Low Unconventional Case, we assume that – primarily because of a lack of public acceptance – only a small share of the unconventional gas resource base is accessible for development. As a result, unconventional gas production in aggregate rises only slightly above current levels by 2035. The competitive position of gas in the global fuel mix deteriorates as a result of lower availability and higher prices, and the share of gas in global energy use increases only slightly, from 21% in 2010 to 22% in 2035, remaining well behind that of coal. The volume of inter-regional trade is higher than in the Golden Rules Case and some patterns of trade are reversed, with North America requiring significant quantities of imported LNG. The Low Unconventional Case reinforces the preeminent position in global supply of the main conventional gas resource-holders.

Energy-related CO2 emissions are 1.3% higher in the Low Unconventional Case than in the Golden Rules Case. Although the forces driving the Low Unconventional Case are led by environmental concerns, this offsets any claim that a reduction in unconventional gas output brings net environmental gains. Nonetheless, greater reliance on natural gas alone cannot realise the international goal of limiting the long-term increase in the global mean temperature to two degrees Celsius above pre-industrial levels. Achieving this climate target will require a much more substantial shift in global energy use. Anchoring unconventional gas development in a broader energy policy framework that embraces greater improvements in energy efficiency, more concerted efforts to deploy low-carbon energy sources and broad application of new low-carbon technologies, including carbon capture and storage, would help to allay the fear that investment in unconventional gas comes at their expense.

The "Golden Rules"

(summarised by the Carnegie Endowment for International Peace)

The "Golden Rules" are principles that can allow governments, industry, and other stakeholders to address the challenges associated with unconventional gas. Improperly addressed, these challenges threaten to hold back, and perhaps halt, the unconventional gas revolution, said [IEA chief economist Fatih] Birol. They are "golden rules" because their application can ensure operators have a "social license to operate" paving the way for a golden age of gas, he explained. He outlined the rules:

1. **Measure, Disclose, and Engage:** The public does not have reliable and up-to-date information about unconventional and shale gas operation. Data on water and air quality should be measured before the start of operations and monitored throughout operations. The type, volume, and effects of the chemicals being used in unconventional gas production ought to be made available. Engagement with communities is important and local communities should feel benefits from the operations.
2. **Watch Where You Drill:** Careful choice of sites can reduce above-ground impacts. It is also important to conduct a survey of geology and seismic activities.
3. **Isolate Wells and Prevent Leaks:** This third rule is crucial because leaks lead to pollution and water contamination, said Birol. Robust rules need to be put on paper for the design and construction of wells and integrity tests of wells should be part of the general performance standard of operations. In addition, appropriate minimum depth limitations should be considered by authorities.
4. **Treat Water Responsibly:** Water is at the heart of shale gas production. Sound management of water resources, reduction of freshwater use, and the need to reuse and recycle water are important.
5. **Eliminate Venting, Minimize Flaring and Other Emissions:** Venting needs to be at zero level and flaring must be minimized. Public authorities may need to consider imposing restrictions on venting and flaring and to minimize emissions.
6. **Be Ready to Think Big:** One has to plan for multiple wells, lots of trucks bringing water to plants, and other upfront investments.
7. **Ensure a Consistently High Level of Environmental Performance:** There is a need for third party assessment through bodies that enjoy public trust, such as universities, academia, and research parties.

Royal Society of London

Shale gas extraction in the UK: a review of hydraulic fracturing

The health, safety and environmental risks associated with hydraulic fracturing (often termed 'fracking') as a means to extract shale gas can be managed effectively in the UK as long as operational best practices are implemented and enforced through regulation. Hydraulic fracturing is an established technology that has been used in the oil and gas industries for many decades. The UK has 60 years' experience of regulating onshore and offshore oil and gas industries.

Concerns have been raised about the risk of fractures propagating from shale formations to reach overlying aquifers. The available evidence indicates that this risk is very low provided that shale gas extraction takes place at depths of many hundreds of metres or several kilometres. Geological mechanisms constrain the distances that fractures may propagate vertically. Even if communication with overlying aquifers were possible, suitable pressure conditions would still be necessary for contaminants to flow through fractures. More likely causes of possible environmental contamination include faulty wells, and leaks and spills associated with surface operations. Neither cause is unique to shale gas. Both are common to all oil and gas wells and extractive activities.

Ensuring well integrity must remain the highest priority to prevent contamination. The probability of well failure is low for a single well if it is designed, constructed and abandoned according to best practice. The UK's well examination scheme was set up so that the design of offshore wells could be reviewed by independent, specialist experts. This scheme must be made fit for purpose for onshore activities. Effects of unforeseen leaks or spills can be mitigated by proper site construction and impermeable lining. Disclosure of the constituents of fracturing fluid is already mandatory in the UK. Ensuring, where possible, that chemical additives are non-hazardous would help to mitigate the impact of any leak or spill.

Concerns have also been raised about seismicity induced by hydraulic fracturing. Natural seismicity in the UK is low by world standards. On average, the UK experiences seismicity of magnitude 5 ML (felt by everyone nearby) every twenty years, andof magnitude 4 ML (felt by many people) every three to four years. The UK has lived with seismicity induced by coal mining activities or the settlement of abandoned mines for a long time. British Geological Survey records indicate that coal mining-related seismicity is generally of smaller magnitude than natural seismicity and no larger than 4 ML. Seismicity induced by hydraulic fracturing is likely to be of even smaller magnitude. There is an emerging consensus that the magnitude of seismicity induced by hydraulic fracturing would be no greater than 3 ML (felt by few people and resulting in negligible, if any, surface impacts). Recent seismicity induced by hydraulic fracturing in the UK was of magnitude 2.3 ML and 1.5 ML (unlikely to be felt by anyone). The risk of seismicity induced by hydraulic fracturing can be reduced by traffic light monitoring systems that use real-time seismic monitoring so that operators can respond promptly.

Monitoring should be carried out before, during and after shale gas operations to inform risk assessments. Methane and other contaminants in groundwater should be monitored, as well as potential leakages of methane and other gases into the atmosphere. The geology of sites should be characterised and faults identified. Monitoring data should be submitted to the UK's regulators to manage potential hazards, inform local planning processes and address wider concerns. Monitoring of any potential leaks of methane would provide data to assess the carbon footprint of shale gas extraction.

The UK's goal based approach to regulation is to be commended, requiring operators to identify and assess risks in a way that fosters innovation and continuous improvement in risk management. The UK's health and safety regulators and environmental regulators should work together to develop guidelines specific to shale gas extraction to help operators carry out goal based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). Risk assessments should be submitted to the regulators for scrutiny and then enforced through monitoring activities and inspections. It is mandatory for operators to report well failures, as well as other accidents and incidents to the UK's regulators. Mechanisms should be put in place so that reports can also be shared between operators to improve risk assessments and promote best practices across the industry.

An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations. Risks should be assessed across the entire lifecycle of shale gas extraction, including risks associated with the disposal of wastes and abandonment of wells. Seismic risks should also feature as part of the ERA.

Water requirements can be managed through integrated operational practices, such as recycling and reusing wastewaters where possible. Options for disposing of wastes should be planned from the outset. Should any onshore disposal wells be necessary in the UK, their construction, regulation and siting would need further consideration.

Wastewaters may contain Naturally Occurring Radioactive Material (NORM) that are present in shales at levels significantly lower than safe limits of exposure. These wastewaters are in need of careful management should NORM become more concentrated during waste treatment. NORM management is not unique to shale gas extraction. NORM is present in waste fluids from the conventional oil and gas industries, as well as in mining industries, such as coal and potash. Much work has been carried out globally on monitoring levels of radioactivity and handling NORMs in these industries.

Shale gas extraction in the UK is presently at a very small scale, involving only exploratory activities. Uncertainties can be addressed through robust monitoring systems and research activities identified in this report. There is greater uncertainty about the scale of production activities should a future shale gas industry develop nationwide. Attention must be paid to the way in which risks scale up. Co-ordination of the numerous bodies with regulatory responsibilities for shale gas extraction must be maintained. Regulatory capacity may need to be increased.

Decisions are soon to be made about shale gas extraction continuing in the UK. The next round of issuing Petroleum Exploration and Development Licences is also pending. This report has not attempted to determine whether shale gas extraction should go ahead. This remains the responsibility of the Government. This report has analysed the technical aspects of the environmental, health and safety risks associated with shale gas extraction to inform decision making. Neither risks associated with the subsequent use of shale gas nor climate risks have been analysed. Decision making would benefit from research into the climate risks associated with both the extraction and use of shale gas. Further benefit would also be derived from research into the public acceptability of all these risks in the context of the UK's energy, climate and economic policies.

German Federal Ministry for the Environment (BMU) and the Federal Environment Agency (UBA)

Umweltauswirkungen von Fracking bei der Aufsuchung und Gewinnung von Erdgas aus unkonventionellen Lagerstätten – Risikobewertung, Handlungsempfehlungen und Evaluierung bestehender rechtlicher Regelungen und Verwaltungsstrukturen

August 2012

We examine the water-related environmental impacts and the risks for human health and the environment that could potentially be caused by hydraulic fracturing (fracking) during exploration and exploitation of unconventional natural gas reservoirs in Germany. This study covers both scientific-technical aspects and the existing mining and environmental regulations. Both were analyzed with respect to consistency, differences and current gaps of knowledge and lack of relevant information.

After a general introduction, this study is divided into four sections: We first focus on the description of geospatial conditions, technical aspects and the chemical additives employed by hydraulic fracturing (Part A) and the existing regulatory and administrative framework (Part B), before we conduct a risk and deficit analysis (Part C) and derive recommendations for further actions and proceedings (Part D).

The foundation of a sound risk analysis is a description of the current system, the relevant effect pathways and their interactions. We describe known and assumed unconventional natural gas reservoirs in Germany based on publicly available information. We present qualitatively the relevant system interactions for selected geosystems and assess potential technical and geological effect pathways.

With regard to the technical aspects, we describe the principles of rock mechanics and provide an overview of the technical fracturing process. In terms of groundwater protection, the key focus is on borehole completion, modelling of fracture propagation and the long-term stability of the borehole (incl. cementation).

The injected fracturing fluids contain proppants and several additional chemical additives. The evaluation of fracturing fluids used to date in Germany shows that even in newer fluids several additives were used which exhibit critical properties and/or for which an assessment of their behaviour and effects in the environment is not possible or limited due to lack of the underlying database. We propose an assessment method which allows for the estimation of the hazard potential of specific fracturing fluids, formation water and the flowback based on legal thresholds and guidance values as well as on human- and ecotoxicologically derived no-effect concentrations.

The assessment of five previously used or prospectively planned fracturing fluids shows

that these selected fluids exhibit a high or a medium to high hazard potential. The flowback redrawn after the pressure release contains fracturing fluids, formation water, and possibly reaction products. Since the formation water can also exhibit serious hazard potentials, environmentally responsible techniques for the treatment and disposal of the flowback is of primary importance.

With respect to groundwater protection, regulatory requirements result from both the mining and the water law. The water law requires the examination, whether concerns can be excluded that hydraulic fracturing and the disposal of flowback may cause adverse groundwater effects. This requires a separate authorization according to the water law. Due to the primacy of the environmental impact assessment directive (EIA Directive, "UVP-Richtlinie") over the national EIA mining regulation ("UVP V-Bergbau") it has already to be assessed in a case-by-case examination, whether an environmental impact assessment is required. The previous administrative practices thus exhibit certain lack of enforcement.

Regulatory deficits exist concerning the application of the requirements of the EIA Directive and concerning some uncertainties in applying specific terms of the water law (groundwater, requirement of and conditions for authorization). We recommend constituting a mandatory environmental impact assessment for all fracking projects in federal law, with a derogation clause for the federal states. The public participation required in the EIA Directive should be extended by a project-accompanying component to improve public access to the assessment of knowledge that is generated after the initial authorization of the project. The examination of the legal requirements should be ensured by clarification and revision of an integrated authorization procedure under the auspices of an environmental authority subordinated to the Ministry of the Environment or by an integration of the mining authority in the environmental administration.

A risk analysis is always site-specific, but must also consider large-scale groundwater flow conditions, which generally requires numerical models. We provide considerations for application of a site-specific generic risk analysis, which integrate both the hazard potential of the fluids and the specific relevance of each effect pathways in the geosystem.

In summary we conclude that basic knowledge and data are currently missing preventing a profound assessment of the risks and their technical controllability (e.g., the properties of the deep geosystem, the behaviour and effects of the deployed chemical additives, etc.). In this setting we propose several recommendations for further action, which we specify for each of the aspects geosystem, technical guidelines and chemical additives.

U.S. Secretary of Energy Advisory Board, U.S. Department of Energy

Shale Gas Production subcommittee: Second 90 day report

November 2011

The Shale Gas Subcommittee of the Secretary of Energy Advisory Board is charged with identifying measures that can be taken to reduce the environmental impact and to help assure the safety of shale gas production. Shale gas has become an important part of the nation's energy mix. It has grown rapidly from almost nothing at the beginning of the century to near 30 percent of natural gas production. Americans deserve assurance that the full economic, environmental and energy security benefits of shale gas development will be realized without sacrificing public health, environmental protection and safety. On August 18, 2011 the Subcommittee presented its initial Ninety-Day Report1 including twenty recommendations that the Subcommittee believes, if implemented, would assure that the nation's considerable shale gas resources are being developed responsibly, in a way that protects human health and the environment and is most beneficial to the nation. The Secretary of Energy's charge to the Subcommittee is included in Annex A andmembers of the Subcommittee are given in Annex B.

A list of the Subcommittee's findings and recommendations follows.

1. Improve public information about shale gas operations: Create a portal for access to a wide range of public information on shale gas development, to include current data available from state and federal regulatory agencies. The portal should be open to the public for use to study and analyze shale gas operations and results.

2. Improve communication among state and federal regulators: Provide continuing annual support to STRONGER (the State Review of Oil and Natural Gas Environmental Regulation) and to the Ground Water Protection Council for expansion of the *Risk Based Data Management System* and similar projects that can be extended to all phases of shale gas development.

3. Improve air quality: Measures should be taken to reduce emissions of air pollutants, ozone precursors, and methane as quickly as practicable. The Subcommittee supports adoption of rigorous standards for new and existing sources of methane, air toxics, ozone precursors and other air pollutants from shale gas operations. The Subcommittee recommends:

4. Enlisting a subset of producers in different basins to design and rapidly

implement measurement systems to collect comprehensive methane and other air emissions data from shale gas operations and make these data publically available;

5. Immediately launching a federal interagency planning effort to acquire data and analyze the overall greenhouse gas footprint of shale gas operations throughout the lifecycle of natural gas use in comparison to other fuels; and

6. Encouraging shale-gas production companies and regulators to expand immediately efforts to reduce air emissions using proven technologies and practices.

7. Protection of water quality: The Subcommittee urges adoption of a systems approach to water management based on consistent measurement and public disclosure of the flow and composition of water at every stage of the shale gas production process. The Subcommittee recommends the following actions by shale gas companies and regulators – to the extent that such actions have not already been undertaken by particular companies and regulatory agencies:

8. Measure and publicly report the composition of water stocks and flow throughout the fracturing and clean-up process.

9. Manifest all transfers of water among different locations.

10. Adopt best practices in well development and construction, especially casing, cementing, and pressure management. Pressure testing of cemented casing and state-of-the-art cement bond logs should be used to confirm formation isolation. Microseismic surveys should be carried out to assure that hydraulic fracture growth is limited to the gas producing formations. Regulations and inspections are needed to confirm that operators have taken prompt action to repair defective cementing jobs. The regulation of shale gas development should include inspections at safety-critical stages of well construction and hydraulic fracturing.

11. Additional field studies on possible methane leakage from shale gas wells to water reservoirs.

12. Adopt requirements for background water quality measurements (e.g., existing methane levels in nearby water wells prior to drilling for gas) and report in advance of shale gas production activity.

13. Agencies should review field experience and modernize rules and enforcement practices to ensure protection of drinking and surface waters.

14. Disclosure of fracturing fluid composition: The Subcommittee shares the prevailing view that the risk of fracturing fluid leakage into drinking water sources through fractures made in deep shale reservoirs is remote.7 Nevertheless the Subcommittee believes there is no economic or technical reason to prevent public disclosure of all chemicals in fracturing fluids, with an exception for genuinely proprietary information. While companies and regulators are moving in this direction, progress needs to be accelerated in light of public concern.

15. Reduction in the use of diesel fuel: The Subcommittee believes there is no technical or economic reason to use diesel in shale gas production and recommends reducing the use of diesel engines for surface power in favor of natural gas engines or electricity where available.

16. Managing short-term and cumulative impacts on communities, land use, wildlife, and ecologies. Each relevant jurisdiction should pay greater attention to the combination of impacts from multiple drilling, production and delivery activities (e.g., impacts on air quality, traffic on roads, noise, visual pollution), and make efforts to plan for shale development impacts on a regional scale. Possible mechanisms include:

(1) Use of multi-well drilling pads to minimize transport traffic and need for new road construction.

(2) Evaluation of water use at the scale of affected watersheds.

(3) Formal notification by regulated entities of anticipated environmental and community impacts.

(4) Preservation of unique and/or sensitive areas as off-limits to drilling and support infrastructure as determined through an appropriate science-based process.

(5) Undertaking science-based characterization of important landscapes, habitats and corridors to inform planning, prevention, mitigation and reclamation of surface impacts.

(6) Establishment of effective field monitoring and enforcement to inform ongoing assessment of cumulative community and land use impacts. The process for addressing these issues must afford opportunities for affected communities to participate and respect for the rights of surface and mineral rights owners.

17. Organizing for best practice: The Subcommittee believes the creation of a shale gas industry production organization dedicated to continuous improvement of best practice, defined as improvements in techniques and methods that rely on measurement and field experience, is needed to improve operational and environmental outcomes. The Subcommittee favors a national approach including regional mechanisms that recognize differences in geology, land use, water resources, and regulation. The Subcommittee is aware that several different models for such efforts are under discussion and the Subcommittee will monitor progress during its next ninety days. The Subcommittee has identified several activities that deserve priority attention for developing best practices:

18. Air: (a) Reduction of pollutants and methane emissions from all shale gas production/delivery activity. (b) Establishment of an emission measurement and reporting system at various points in the production chain.

19. Water: (a) Well completion – casing and cementing including use of cement bond and other completion logging tools. (b) Minimizing water use and limiting vertical fracture growth.

20. Research and Development needs. The public should expect significant

technical advances associated with shale gas production that will significantly improve the efficiency of shale gas production and that will reduce environmental impact. The move from single well to multiple-well pad drilling is one clear example. Given the economic incentive for technical advances, much of the R&D will be performed by the oil and gas industry. Nevertheless the federal government has a role especially in basic R&D, environment protection, and safety. The current level of federal support for unconventional gas R&D is small, and the Subcommittee recommends that the Administration and the Congress set an appropriate mission for R&D and level funding.

Massachusetts Institute of Technology

The future of Natural Gas: An interdisciplinary MIT study

2011

Major Findings and Recommendations: Supply

Globally, there are abundant supplies of natural gas, much of which can be developed at relatively low cost. The mean projection of remaining recoverable resource in this report is 16,200 Tcf, 150 times current annual global natural gas consumption, with low and high projections of 12,400 Tcf and 20,800 Tcf, respectively. Of the mean projection, approximately 9,000 Tcf could be developed economically with a natural gas price at or below $4/Million British thermal units (MMBtu) at the export point.

Unconventional natural gas, and particularly shale gas, will make an important contribution to future U.S. energy supply and CO2 emission reduction efforts. Assessments of the recoverable volumes of shale gas in the U.S. have increased dramatically over the last five years, and continue to grow. The mean projection of the recoverable shale gas resource in this report is approximately 650 Tcf, with low and high projections of 420 Tcf and 870 Tcf, respectively. Of the mean projection, approximately 400 Tcf

could be economically developed with a natural gas price at or below $6/MMBtu at the wellhead. While the pace of shale technology development has been very rapid over the past few years, there are still many scientific and technological challenges to overcome before we can be con fident that this very large resource base is being developed in an optimum manner.

Although there are large supplies, global conventional natural gas resources are concentrated geographically, with 70% in three countries: Qatar, Iran and Russia. There is considerable potential for unconventional natural gas supply outside North America, but these resources are largely unproven with very high resource uncertainty. Nevertheless, unconventional supplies could provide a major opportunity for diversification and improved security of supply in some parts of the world.

The environmental impacts of shale development are challenging but manageable. Shale development requires large-scale fracturing of the shale formation to induce economic production rates. There has been concern that these fractures can also penetrate shallow freshwater zones and contaminate them with fracturing fluid, but there is no evidence that this is occurring. There is, however, evidence of natural gas migration into freshwater zones in some areas, most likely as a result of substandard well completion practices by a few operators. There are additional environmental challenges in the area of water management, particularly the effective disposal of fracture fluids. Concerns with this issue are particularly acute in regions that have not previously experienced large-scale oil and natural gas development, especially those overlying the

massive Marcellus shale, and do not have a well-developed subsurface water disposal infrastructure. It is essential that both large and small companies follow industry best practices; that water supply and disposal are coordinated on a regional basis and that improved methods are developed for recycling of returned fracture fluids.

Natural gas trapped in the ice-like form known as methane hydrate represents a vast potential resource for the long term. Recent research is beginning to provide better definition of the overall resource potential, but many issues remain to be resolved. In particular, while there have been limited production tests, the longterm producibility of methane hydrates remains unproven, and sustained research will be required.

MAJOR RECOMMENDATIONS

Government-supported research on the fundamental challenges of unconventional natural gas development, particularly shale gas, should be greatly increased in scope and scale. In particular, support should be put in place for a comprehensive and integrated research program to build a system-wide understanding of all subsurface aspects of the U.S. shale resource. In addition, research should be pursued to reduce water usage in fracturing and to develop cost-effective water recycling technology.

A concerted coordinated effort by industry and government, both state and Federal, should be organized so as to minimize the environmental impacts of shale gas development through both research and regulation. Transparency is key, both for fracturing operations and for water management. Better communication of oil- and gas-field best practices should be facilitated. Integrated regional water usage and disposal plans and disclosure of hydraulic fracture fluid components should be required.

The U.S. should support unconventional natural gas development outside U.S., particularly in Europe and China, as a means of diversifying the natural gas supply base.

The U.S. government should continue to sponsor methane hydrate research, with a particular emphasis on the demonstration of production feasibility and economics.

University of Texas

Fact-based regulation for environmental protection in shale gas development

February 2012

The findings of this exploration of shale gas regulation are summarized starting with an overview of shale gas followed by a description of media coverage and public perception of its development. The science of shale gas impacts is then reviewed, and the regulatory framework – and the enforcement of regulations – are described. Finally, the compiled results of the investigation are interpreted for future fact-based regulation of shale gas development.

Shale gas is considered an unconventional gas resource because in conventional exploration and development it is understood that natural gas originates in shale as a "source rock" but that it must migrate into porous and permeable formations (termed "reservoirs"), such as sandstones, in order to be produced economically. Shale gas production involves going directly to the source rock to access the resource. Such production from shale units was not considered economically feasible before application and refinement of horizontal drilling and hydraulic fracturing.

Shale units capable of producing natural gas in large quantities are found in five regions of the continental US. They are shown below with the shale plays and percent of US resources:

- Northeast: primarily the Marcellus (63%)
- Gulf Coast: Haynesville, Eagle Ford (13%)
- Southwest: Barnett and Barnett-Woodford (10%)
- Mid-Continent: Fayetteville, Woodford (8%)
- Rocky Mountain: primarily Mancos and Lewis (6%)

The use of hydraulic fracturing to increase production from conventional oil and gas wells grew rapidly starting in the late 1940s and continues to be used routinely for reservoir stimulation. Since its initiation, hydraulic fracturing has been used to stimulate approximately a million oil and gas wells. Improvements in horizontal drilling technologies, such as downhole drilling motors and telemetry equipment, led to its increased application in conventional drilling starting in the early 1980s. A partnership between agencies of the US government, a gas industry consortium, and private operators beginning in the 1970s led to the development of horizontal drilling and multi-stage hydraulic fracturing, which were critical to economic production of shale gas. The development efforts of Mitchell Energy Corporation in the Barnett shale in Texas during the 1980s and 1990s were critical in the commercial success of shale gas production.

Shale gas has become embroiled in controversy over alleged impacts on public health and the environment. Some segments of the public have become deeply suspicious of the veracity and motives of gas companies. These suspicions were intensified by the natural gas producers and gas field service companies initially refusing to disclose the chemical makeup of fluids used to enhance hydraulic fracturing. Many outside observers have concluded that it is "likely", "highly likely" or "definitively proven" that shale gas extraction is resulting in widespread contamination of groundwater in the US. For example, one study of the impacts of shale gas exploitation in the US asserted that "there is considerable anecdotal evidence from the US that contamination of both ground and surface water has occurred in a range of cases". In another example, a university professor stated in a written submission to the EPA that "Shale gas development clearly has the potential to contaminate surficial groundwater with methane, as shown by the large number of incidences of explosions and contaminated wells in Pennsylvania, Wyoming, and Ohio in recent years." and that "… shale gas development has clearly contaminated groundwater and drinking water wells with methane…".

The response from the gas industry and its supporters has generally been denial – not only that any such problems exist but also that if they did exist they are not real risks. For example, one industry website denied that the migration of fracturing fluid underground is among the "environmental and public health risks" of hydraulic fracturing and shale development. In another example, a university professor who is a shale gas proponent told a Congressional Committee that "the hydraulic fracturing process is safe, already well regulated by the various States" and that "the hysterical outcry over this process is completely unjustified".

The debate between protagonists and antagonists of shale gas development has in some cases become strident and acrimonious. Negative perceptions and political consequences have led to the prohibition of shale gas development in a number of instances, at least temporarily. Realization on the part of all stakeholders of the large national energy security and other benefits of shale gas resource – when developed with adequate protection of public health and the environment – may provide "common cause" for seeking solutions.

The most rational path forward is to develop fact-based regulations of shale gas development based on what is currently known about the issues and, at the same time, continue research where needed for information to support controls in the future. Additional or improved controls must not only respond to the issues of controversy, but also address the full scope of shale gas development. Priorities must be set on the most important issues as well as on public perceptions. The path ahead must take advantage of the substantial body of policies and regulations already in place for conventional oil and gas operations. Enforcement of current and future regulations must also be ensured to meet the twin objectives of protection of environment and other resources and gaining public acceptance and support.

The Horinko Group

Hydraulic fracturing: Guidebook on the current future environmental, regulatory, and legal challenges

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While there are many unknowns surrounding the ever-heightened hydraulic fracturing debate, there is clarity on a few aspects. First, the economic potential that the development of U.S. natural gas supply holds is undeniable. The vast unconventional reserves—now accessible with the technologies of hydraulic fracturing and horizontal drilling—have led to job creation, decreased energy costs, reduced dependence on foreign oil, and if exported, could come to bear on the balance of trade and improve the U.S.'s international negotiating position. It is also generally agreed that natural gas for electricity generation is a cleaner burning fuel—with fewer air pollutants and greenhouse gas emissions—than coal power. Given their promise and proven contributions to the U.S. energy supply, the technologies of hydraulic fracturing and horizontal drilling should be explored with a goal toward safe, environmentally sound development.

The risks of these practices, however, are yet to be fully known. The lack of concrete information has led to public distrust, restrictive regulation, litigation, and, in some cases, outright bans. For these results to be avoided, industry must be proactive in self-regulation and sensitive to concerns. This must go beyond simple compliance with regulations now in place. For the industry to gain the public's trust, it must follow best practices and standards that are available, and in general, proceed with care and attentiveness to the influence of operations on the environment and communities. In particular, focus must be placed on finding and implementing innovative methods or technologies for minimizing impact on water resources and reusing waste generated. Where reuse is not possible, proper disposal is absolutely essential. Transparency, provision of data, and collaboration, especially as academics and regulators seek stronger empirical evidence, will determine the fate of the industry.

Non-governmental organizations, universities, and scientific institutions researching the vital questions surrounding hydraulic fracturing must also uphold standards of transparency, especially when it comes to presenting empirical evidence and diagnosing uncertainties fairly. Matters of definitional discrepancy must not be exploited, and a more concerted effort must be made by reporting bodies to present the information clearly and concisely. The goal should be public understanding, not simply public pronouncements.

Regulatory bodies, both state and federal, must take a careful look at the evidence presented and the tools available, using the best science to inform decisions. States should utilize review programs like STRONGER to ensure their regulations are adequate and be ready and willing to implement new rules as new evidence dictates. They must also work closely with the federal government. EPA and other federal agencies must likewise be ready and willing to integrate feedback from states, industry, and researchers into their decisions. As with the new NSPS standards, both state and industry must participate in reshaping and informing federal regulation.

The federal government has already taken some strides toward a collaborative approach to this issue with the formation of the *Interagency Working Group to Support Safe and Responsible Development of Unconventional Domestic Natural Gas Resources*. This body was established following an Executive Order from the President on Aril 13, 2012 and consists of thirteen federal agencies tasked with coordinating policy activities, sharing of scientific environmental, technical and economic information, long-term planning for natural resource assessment and infrastructure development, and promoting interagency communication.

Where further federal regulations are under consideration, decision-makers must uphold a flexible, adaptable, and collaborative approach, and other stakeholders, including states, industry, academia, and NGOs, must participate fully. It is possible that many aspects of this issue are best regulated at the state level where regulators have the necessary familiarity with local conditions, geology, industry characteristics, legal structures, and economics. In areas where pollutants know no legal boundaries, as with air and water, and in cases where inconsistencies in state regulations jeopardize natural resources and human health, there may be a real need for the establishment of consistent standards and protections nationwide. Any new federal regulations must be based on sound science, retain flexibility for states or operational differences, be adaptable as the surrounding science becomes stronger, and strive to keep the processes of permitting and compliance as streamlined as possible to increase accountability and enforceability while maintaining cost efficiency. In this way, the continued development of this industry with minimal impacts on the environment and natural resources, negligible impacts to human health, and maximum benefits to communities and citizens across the nation and across the globe, remains within reach.

Key Take-Aways

The following summarizes the key take-aways from The Horinko Group's Guidebook on Hydraulic Fracturing:

Adaptability & Flexibility

- Flexibility of regulations as scientific certainty evolves
- Regulation tailored to diversity across industry
- Willingness of industry practitioners to adopt changes as best practices and new technologies emerge

Transparency & Reliance on Sound Science

- Industry must remain open and honest about its practices
- Research and regulation based on unbiased data and sound science
- Present information clearly to the public to prevent an uninformed and unproductive dialogue

Innovative Research

- Continued pursuit of creative solutions to environmental issues, especially as related to mitigating the burden on water resources and managing wastewater
- Continued investment in renewable resources by government and industry

Collaboration

- Build on the experience and expertise of others
- Dissemination of best practices that mitigate environmental detriment while enabling industrial growth
- Identification of the most critical research needs and the steps needed to address them
- Sharing of scientific, technical, economic, legal, and long-term planning information